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Changes in sleep, mood and subjective and objective responses to physical performance during the daytime in Ramadan

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Twenty healthy young males were studied in Libya over a period one week before Ramadan to one week after it. Control values were obtained from the weeks before and after Ramadan, and experimental values from the first and last weeks of Ramadan. Participants answered a questionnaire about their sleep and naps, the food and fluid ingested, and activities they had undertaken. They also gave a urine sample for measurement of osmolality, measured grip strength and performed a 15-min bout of exercise. The rise in heart rate and perceived exertion during exercise and blood lactate after exercise were measured. Nocturnal sleep and daytime dehydration, activities and sleepiness, perceived exertion when exercise was undertaken, lactate metabolism and responses to physical activity all changed during Ramadan. In addition, there were compensatory changes after sunset. These results contribute to an understanding of physiological changes during Ramadan in healthy individuals.

Keywords: drinking; eating; sleepiness; physical performance; mental performance; social activity

Introduction

Devout Muslims abstain from food and fluid intake between sunrise and sunset during the month of Ramadan. Such a change produces many effects upon an individual's physiology, biochemistry and behaviour (reviewed in Leiper et al. 2003; Roky et al. 2004; Benaji et al. 2006; Reilly and Waterhouse 2007).

It has been shown that sleep is shorter at night during Ramadan (Roky et al. 2003), and increased amounts of sleep are taken during the daytime to reduce sleepiness (Margolis and Reed 2004). Mood and the willingness to work decrease (Karaagaoglu and Yucecan 2000), as do abilities to perform physical and mental activities optimally (Kadri et al. 2000; Roky et al. 2000). Increased frequencies in road traffic accidents have sometimes been reported (Roky et al. 2004), and there are several metabolic changes (Qujeq et al. 2002; Roky et al. 2004). Many of these changes – including those to the circadian rhythms of core temperature (Roky et al. 2000) and several hormones (Bogdan et al. 2001) – have been attributed to the altered distribution of the hours of sleeping and waking.

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Most of these studies have concentrated on changes taking place during the course of the four weeks of Ramadan rather than the course of individual days (Reilly and Waterhouse 2007). However, it is known that individuals tend to prepare for the period of fasting during Ramadan by rising earlier and eating a meal before sunrise; also, after sunset, a wide variety of food and fluids is taken in as individuals replenish energy and fluid levels and then retire later than normal (Karaagaoglu and Yucecan 2000). These changes to individuals' feeding habits as well as their sleep–wake cycle would be predicted to affect their physiology and metabolism.

Previous work by our group on changes during Ramadan (Waterhouse et al. 2008a, 2008b) investigated individuals' subjective feelings and responses to food and fluid during the course of individual days. Less physical, mental and social activities were performed in the daytime, but there were significant *increases* after sunset. Similarly, daytime fasting was compensated for by increased fluid and food intakes in the hours before sunrise and, particularly, after sunset. In addition, sleep at night was altered in Ramadan, daytime sleepiness increased and more naps were taken in the daytime, the reason often cited for this being to catch up on lost sleep.

The present study has investigated in more detail the changes during Ramadan in subjective estimates of nocturnal sleep, measures of changes in hydration status and grip strength, and responses to a set bout of mild exercise. The choice of measures of physical activity, as well as the exact times of testing, were restricted by the fact that the participants were all students undertaking a full schedule of studies.

Methods

Participants and familiarisation

The experiment was performed at the Alahli Football Club (Tripoli, Libya), an academy for training in Sports Sciences. It took place in the weeks before, during and after Ramadan, 2008. (Ramadan in 2008 was from 31 August to 30 September; sunrise was about 05:30 h and sunset about 19:30 h, local time). Participants were recruited by advertisement in the University and by word-of-mouth. The aims and a general outline of the protocol were explained to them, and any questions were answered. The study was approved by the Research Ethics Committee of Liverpool John Moores University.

Potential participants who showed an interest in the project were then required to take part in a familiarisation day at the Academy. During this occasion, anthropometric data were collected, it was determined which was the dominant hand, the questionnaires that would be answered and subjective information that would be required were explained, and participants practised on the cycle ergometer, adjusting the saddle height, and so on.

Twenty individuals agreed to take part in the study; they signed informed consent forms in the presence of a third, disinterested party. None was a smoker or taking chronic medication. All were male and aged 18; their mean (SD) height was 1.74 (0.06) m and body mass 66.4 (6.2) kg.

During the experiment itself, the participants were required to attend the laboratory on four separate days. For the 48 h before each of these days, they were required to follow normal times of going to bed and getting up, and not to undergo any period of severe or extended exercise. The four experimental days were: once in the week before Ramadan, twice during Ramadan (once in the first two weeks and

once in the last two weeks), and finally during the week after Ramadan (after any celebrations associated with Eid had finished).

Protocol and measurements

On each experimental day, participants were asked to attend the laboratory at 09:00 h, 12:00 h, 17:00 h and 21:00 h. The protocol at each of these times was as follows. Participants rested quietly for 30 min, during which time the questionnaire was answered and resting heart rate (if applicable, see below) was measured. In the 09:00 h, 12:00 h and 17:00 h sessions, a urine sample was then given. In the 12:00 h and 17:00 h sessions, grip strength was measured next and participants then undertook the bout of cycling. Immediately after the exercise, heart rate was measured again and a sample of blood was taken by pin-prick.

Questionnaire

Figure 1a (based on Waterhouse et al. 2008a) shows the questionnaire for 09:00 h, which required information about the previous night's sleep (section A), fluid intake (section B), food intake (section C) and activities (section D) before sunrise. The questionnaires at 12:00 h, 17:00 h and 21:00 h asked for the same information but applied to the intervals since the previous questionnaire. That is, the questionnaires at 12:00 h and 17:00 h included periods of fasting (in Ramadan) and that at 21:00 h, information about activities after sunset. For these last three times, section A was modified (Figure 1B) and questions about daytime naps rather than nocturnal sleep were asked. For many of the questions, participants were required to state not only if they had/had not performed a particular action (taken a nap, for example) but also their reasons for this choice.

Interpretation of the exact meaning of any question was left to participants to decide for themselves, although it was explained that the interpretation should be consistent throughout the study. Strict anonymity was guaranteed with regard to the answers given. Participants were asked not to refer back to previous answers and the results from all questionnaires were collected (by HA) at the end of the study.

''Fluid scores'' and ''food scores'' were calculated for each participant and time interval. These scores ranged from 0 to 4 and were semi-quantitative estimates of total fluid or food intake during this interval. For the fluid intake score (see Figure 1a, section B): ''0'' represented no intake; ''1'' indicated a ''sip''; ''2'', less than 1 glass/cupful; ''3'', 1 glass/cupful; and ''4'', more than 1 glass/cupful. For the food intake score (section C): ''0'' represented no intake; ''1'' indicated a ''snack''; ''2'', a ''small meal''; ''3'', a medium-sized meal; and ''4'', a large meal.

In a preliminary analysis, it was shown that the answers from the two control weeks (before and after Ramadan) did not show any significant differences, and so they were pooled for each participant (''Controls''). Similarly, the results from the two weeks of Ramadan were not significantly different, and so the average values for these were calculated for each participant (''Ramadan'').

For many of the variables (whether or not a sleep was taken, whether or not a drink was taken, and the reasons for making such choices, for example), the ''fraction of possible occasions'' was calculated for each participant. ''Possible occasions'' was calculated as follows. Suppose, for example, that, during one of the time intervals, a participant had eaten on only one of the two days, the fraction of

(a)

A. SLEEP:
1. Estimated time of retiring……..
2. Estimated time of rising……

(For questions 3a-3e, place a mark on the lines to indicate your responses):
3. Last night's sleep, when compared with normal:

a. How easily did you get to sleep?
-5 ---------- 0 ---------- +5
much less easily — normal — much more

b. What time did you get to sleep?
-5 ---------- 0 ---------- +5
earlier — normal — later

c. How well did you sleep?
-5 ---------- 0 ---------- +5
more waking episodes — normal — fewer waking episodes

d. What was your waking time?
-5 ---------- 0 ---------- +5
earlier — normal — later

e. How alert did you feel 30 min after rising?
-5 ---------- 0 ---------- +5
less — normal — more

f. Did you eat or drink anything in the hour before going to bed? (Ring one)
1. No
2. A drink only
3. A snack
4. A small meal.

g. If you ate or drank anything, do you think it helped you sleep? (Ring one)
1. No
2. A little
3. A lot

B. DRINK:
4. Did you drink anything since waking time? (Ring one answer)
YES NO

If you answered YES, go to question 5. If you answered NO, go to question 8.

5. How much did you drink? (Ring as many answers as apply)
a. one sip or mouthful
b. less than one glass or cupful
c. one glass or cupful
d. more than one glass or cupful

6. What did you drink? (Ring as many answers as apply)
a. water
b. tea or coffee
c. fruit juice
d. fizzy drink
e. milk

7. Why did you drink? (Ring as many answers as apply)
a. I felt thirsty
b. I was with a friend and being sociable
c. For health reasons (including having my period)

Go to Section C, FOOD

8. Why did you NOT drink? (Ring as many answers as apply)
a. I did not feel thirsty
b. I never drink at this time
c. I was too busy
d. I am not allowed to drink during this time

C. FOOD:
9. Did you eat anything during this time? (Ring one answer)
YES NO
If you answered YES, go to question 10. If you answered NO, go to question 12.

10. How much did you eat? (Ring one answer)
a. snack
b. small meal
c. medium sized meal
d. large meal

Figure 1. (a) Questionnaire; (b) Section A of questionnaire given during the daytime. For more details, see text.

11. Why did you eat? (Ring as many answers as apply)
a. I felt hungry
b. I was being sociable
c. I was preparing for times when I would not eat
d. for health reasons (including having my period)

Go to Section D, Activities and Feelings.

12. Why did you not eat? (Ring as many answer as apply)
a. I did not feel hungry
b. I never eat at this time
c. I was too busy
d. I am not allowed to eat during this time

D. ACTIVITIES AND FEELINGS:
The answers to questions 13 - 18 are a number from 0 to 4, where:
0 means "not at all"
1 means "slightly"
2 means "moderately"
3 means "quite a lot"
and 4 means "very much"

13. How physically active have you been? (ANSWER 0 - 4)…..

14. How mentally active have you been? (ANSWER 0 - 4)…..

15. How socially active have you been? (ANSWER 0 - 4)…..

16. How sleepy do you now feel? (ANSWER 0 - 4)…..

17. How able to perform physical tasks do you now feel? (ANSWER 0 - 4)…..

18. How able to perform mental tasks do you now feel? (ANSWER 0 - 4)…..

(b)

A. SLEEP:
1. Did you sleep during this time? (Ring one answer)
YES NO

If you answered YES, go to question 2. If you answered NO, go to question 4.

2. About how long did you sleep? (answer in hours)……..

3. Why did you sleep? (Ring as many answers as apply)
a. I felt tired
b. I was bored
c. I wanted to catch up on lost sleep

Go to question Section B, DRINK

4. Why did you NOT sleep? (Ring as many answers as apply)
a. I did not feel tired
b. I never do sleep at this time
c. I was too busy
d. I am not allowed to sleep

Figure 1. (*Continued*).

possible occasions when a meal was eaten would then be 0.5. Further, and continuing with this example, when the fraction of possible occasions that a particular reason for eating was calculated, the frequency of occurrence of this reason was expressed as a fraction of the single possible occasion (as food was eaten on only one day); similarly, when the fraction of possible occasions that a particular reason for not eating was calculated, the frequency of occurrence of this reason was expressed as a fraction of one possible occasion (the single day when food intake had not taken place). This approach could not be used if an individual did not perform an action during a particular time interval on either of the two days (never slept between 09:00 h and 12:00 h, for example); in this case, it would be meaningless to ask about the reasons for sleeping, although it would be possible to use the results from both days to assess the reasons for not sleeping.

Physiological measures

Heart rate was monitored at 12:00 h and 17:00 h, before and immediately after the bouts of exercise. A heart rate monitor (Polar, Kempele, Finland) was strapped to the chest and a data logger attached to the participant's wrist. A resting heart rate was measured at the end of the 20 min after having answered the questionnaire (Figure 1a, 1b) and before giving the urine sample and measuring grip strength. Heart rate was also measured a second time in the 30 sec immediately after the bout of exercise.

Urine samples were given three times per day (at 09:00 h, 12:00 h and 17:00 h); an aliquot (50 ml) was stored at 10°C until later analysis for osmolality (Osmocheck pocket pal OSMO, Vitech Scientific Ltd, Japan).

Grip strength was measured at 12:00 h and 17:00 h (Handgrip Dynamometer TRK5106. Jump MD, Tarek Scientific Instrument Score, Japan). Three measurements were taken from the dominant and non-dominant hand, and the highest of each set of three values was used for subsequent analysis.

The bout of exercise consisted of cycling for 15 minutes on a cycle ergometer (Monark Ergo medic 828E Test Cycle, Electronic Company, Sweden) at a constant load of 120 watts. The rate of turning the pedals, the cadence, was left to individual choice – the higher the cadence, the lower the force that had to be exerted on the pedals. (The cadence was calculated as the number of "steps" taken per minute, such that a cadence of, say, 80, meant that the pedals had been turned 40 times.)

After the exercise, an estimate of perceived exertion was made on the Borg scale (Borg 1962). Also, a drop of blood was taken from the finger tip by pin-prick, and blood lactate was analysed using a Lactate Pro Test Meter (model LT7010, Arfray Inc., Kyoto, Japan).

Statistics

Comparisons between control days and Ramadan for nocturnal sleep times were made by paired *t*-tests. Wilcoxon's *z* was calculated for comparisons between the non-parametric variables: sleep quality, frequencies of taking different types of drink, and fractions of possible occasions given for reasons when not sleeping, drinking or eating.

Analysis of variance with repeated measures was used for the other measures. The main factors were Day (two levels, Controls vs. Ramadan) and Time of Day (2–4 levels, including: rising–09:00 h, t_1; 09:00–12:00 h, t_2; 12:00–17:00 h, t_3; and after sunset, t_4). The additional factor Hand (dominant vs. non-dominant) was used for grip strength. Greenhouse–Geiser corrections were used, and significant differences within the main factors were assessed using Bonferroni corrections.

The SPSS package, version 14, was used. Significance was set as $P < 0.05$, though occasions where $0.05 < P < 0.10$ have been reported as "marginally significant". Exact *P* values have been given; results given as "0.000" in the statistics output have been reported as "< 0.0005".

Results

In a preliminary analysis (referred to above), results from the two control days were compared, as well as from the two Ramadan days. For no variable was there

a significant difference between the pair of days ($P > 0.10$ in all cases). Therefore, the data from the two days were pooled, and all further analyses are based upon the means of the two Control and Ramadan days.

Results from questionnaires

Nocturnal sleep (Section A, Figures 1a, 1b)

Estimates of nocturnal sleep times (Questions 1 and 2, Section A, Figure 1a) indicated that participants went to bed and rose later in Ramadan. Mean (SE) times of retiring on control days were 23 h 25 min (13 min) and, in Ramadan, 02 h 16 min (20 min); $t_{19} = 8.8$, $P < 0.0005$. Rising times were 09 h 30 min (11min) and 10 h 15 min (7 min) for controls and Ramadan, respectively ($t_{19} = 3.9$, $P = 0.001$). Total time spent in bed fell from 10 h 05 min (12 min) on control days to 7 h 59 min (17 min) in Ramadan ($t_{19} = 7.2$; $P < 0.0005$).

Subjective estimates of sleep quality and associated factors (Question 3, Section A, Figure 1a) were compared between control days and Ramadan. Results confirmed that participants felt they got to sleep later in Ramadan ($z = 2.09$, $P = 0.036$); mean wake times were not significantly different ($z = 0.32$; $P = 0.75$). The ease of getting to sleep was felt to be greater in Ramadan ($z = 2.54$; $P = 0.011$) but sleep was not significantly more refreshing ($z = 0.27$; $P = 0.79$). Alertness 30 min after waking was not significantly different ($z = 1.62$; $P = 0.11$). Food and fluid intake just before retiring tended to increase in Ramadan ($z = 1.88$; $P = 0.061$) and it was generally felt that the value of intake of food at this time for promoting sleep was higher than on control days ($z = 2.01$; $P = 0.044$).

Diurnal naps

During the daytime, naps (see Section A, Figure 1b) were taken too infrequently to be analysed statistically. However, the reasons for NOT sleeping could be analysed (Figure 2). In the daytime (09:00 h – 17:00 h), ''Not Tired'' and ''Never do'' were given as reasons less frequently in Ramadan ($z = 2.65$, $P = 0.008$ and $z = 2.54$, $P = 0.011$, respectively); ''Too busy'', which was the reason most commonly given, was even more frequent in Ramadan ($z = 2.88$, $P = 0.004$). In the evenings (17:00 h – 21:00 h), the reasons ''Not tired'' and ''Never do'' were cited most frequently, but not with significantly different frequencies on control days and during Ramadan; citing ''Too busy'' was marginally more frequent in Ramadan ($z = 1.93$, $P = 0.053$) but it was still cited on only about 20% of possible occasions.

Fluid and food intake

Since fluid and food intake are not allowed between sunrise and sunset in Ramadan, comparisons at 12:00 h and 17:00 h between intakes on control days and in Ramadan would be meaningless. *A priori*, it was thought that comparisons at both 09:00 h and 21:00 h would be useful, since they would indicate preparations for, and recovery from, the period of fasting. However, the participants' responses at 09:00 h indicated that no fluid or food had been taken in during Ramadan. This result means that participants' responses did not include anything taken in after rising but before sunrise. Therefore, investigations of any preparations for fasting were precluded.

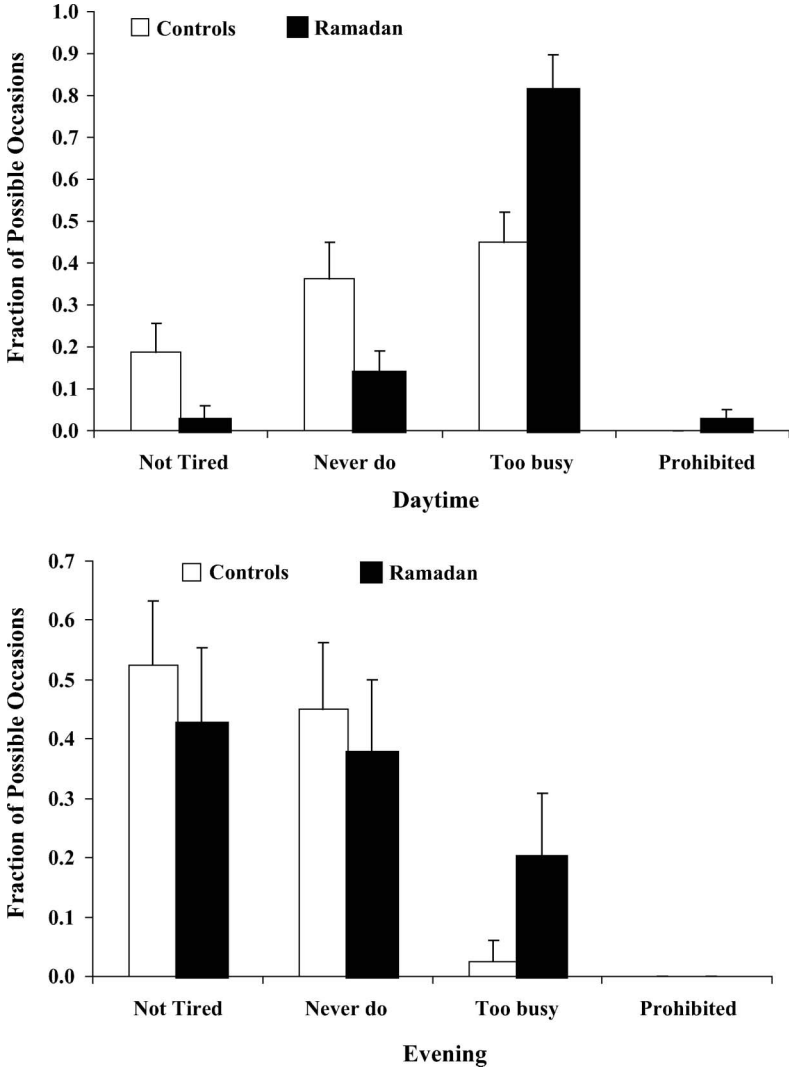

Figure 2. Reasons given for not napping, top, in the daytime; bottom, in the evening. For explanation of "Fraction of Possible Occasions", see text.

By contrast, it was possible to compare intakes at 21:00 h, when eating and drinking behaviour indicative of recuperation from fasting were present. All participants drank in the evening, with mean (SE) fluid scores of 3.85 (0.05) and 3.73 (0.09) on controls days and during Ramadan, respectively. These scores reached towards the maximum possible of 4.0, indicating more than one glass or cup of fluid was drunk (Figure 1a, Q.5). Figure 3, top, shows that water, fruit juice and fizzy drinks were consumed most frequently, and coffee or tea were rarely drunk. In Ramadan, the frequency of drinking water increased significantly ($z = 2.14$, $P = 0.032$) and of drinking fizzy drinks decreased significantly ($z = 2.81$, $P = 0.005$). There was a non-significant rise in drinking milk in Ramadan ($z = 1.56$; $P = 0.12$). The main reasons for drinking on control days (Figure 3, bottom) were "thirst" and "being sociable"; "thirst" became a more important

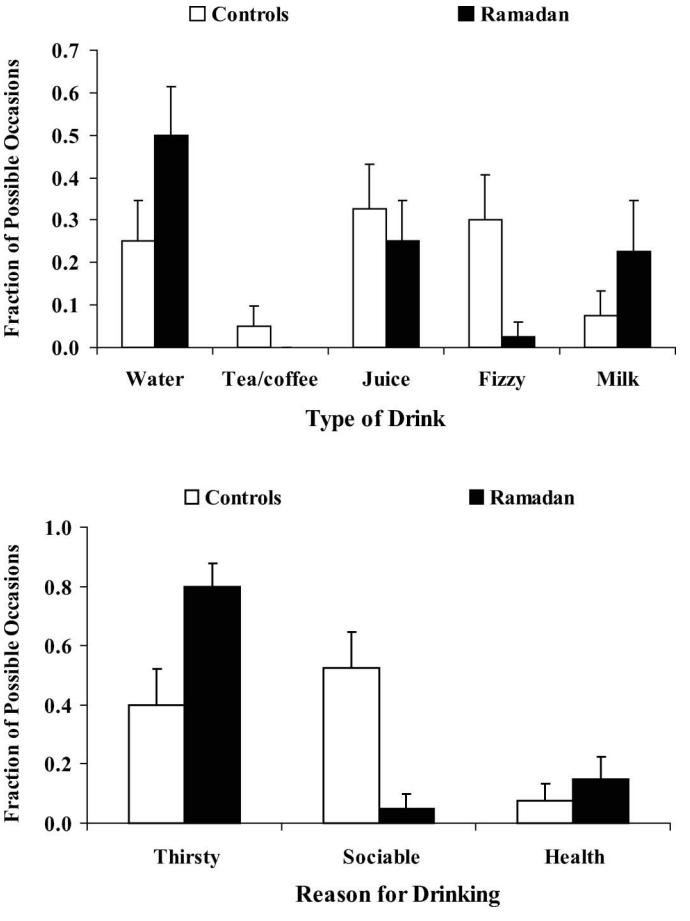

Figure 3. Top, type of drink taken in the evening on control days and during Ramadan. Bottom, reasons given for drinking. For explanation of "Fraction of Possible Occasions", see text.

reason during Ramadan ($z = 2.89$, $P = 0.004$), at the expense of "being sociable" ($z = 3.42$, $P = 0.001$).

All participants ate in the evening, with mean (SE) food scores of 3.58 (0.13) and 3.08 (0.13) on controls days and during Ramadan, respectively. These scores indicated that meals were generally either medium (score = 3) or large (score = 4) (Figure 1a, Q.10). Figure 4 shows that "hunger" and "being sociable" were both cited quite frequently on control days. However, "being sociable" decreased significantly during Ramadan ($z = 2.84$, $P = 0.005$) and "recovery from fasting" increased significantly as a reason and became cited more frequently than "being sociable" ($z = 2.07$, $P = 0.038$).

Subjective estimates of activities and sleepiness (Section D, Figure 1a)

Figure 5 shows the mean physical activity (top), social activity (middle) and sleepiness (bottom) scores at the four times of testing on control and Ramadan days. Physical activity was least before 09:00 h (t_1), and activity during the daytime (t_2-t_3)

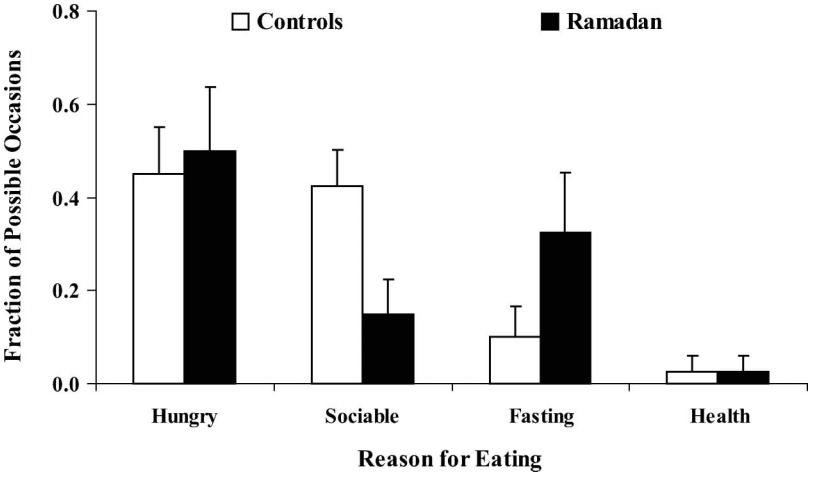

Figure 4. Reasons for eating in the evening on control days and during Ramadan. For explanation of "Fraction of Possible Occasions", see text.

was greater than after sunset (t_4). There was no significant effect of Day but a highly significant effect of Time and interaction between Time x Day (Table 1). The significant interaction reflects the tendencies for lower activities in Ramadan during the daytime and higher activities before and after sunset. Similar profiles were observed for mental activities and for the desires to perform physical or mental work. In all cases, scores were higher in the daytime than in the early morning and tended to fall in the evening; the effect of Ramadan was to decrease daytime values and increase the evening value.

Social activity scores showed a slightly different profile (Figure 5, middle, and Table 1). Activity was lowest in the morning and tended to rise throughout the day. This profile was more marked in Ramadan, with peak activities in the evening (the interaction between Time x Day being marginally significant). Sleepiness (Figure 5, bottom, and Table 1) tended to show a profile that was the inverse of the other variables; values fell in the daytime and rose towards evening. However, the evening rise in sleepiness was much less marked in Ramadan, accounting for the significant interaction between Time x Day (Table 1).

Urine osmolality

On control days, the osmolality of the urine showed similar values throughout the daytime and indicated (a normal degree of) mild dehydration (Figure 6). During Ramadan, by contrast, whilst the values were very similar to control days at 09:00 h, they increased throughout the day to reach a value indicative of increased dehydration by 17:00 h. This difference in profile between the two types of day accounts for the significant statistical differences that were observed (Table 1).

Physical measures

Mean grip strengths of both dominant and non-dominant hands showed no significant differences between control days and Ramadan but a significant

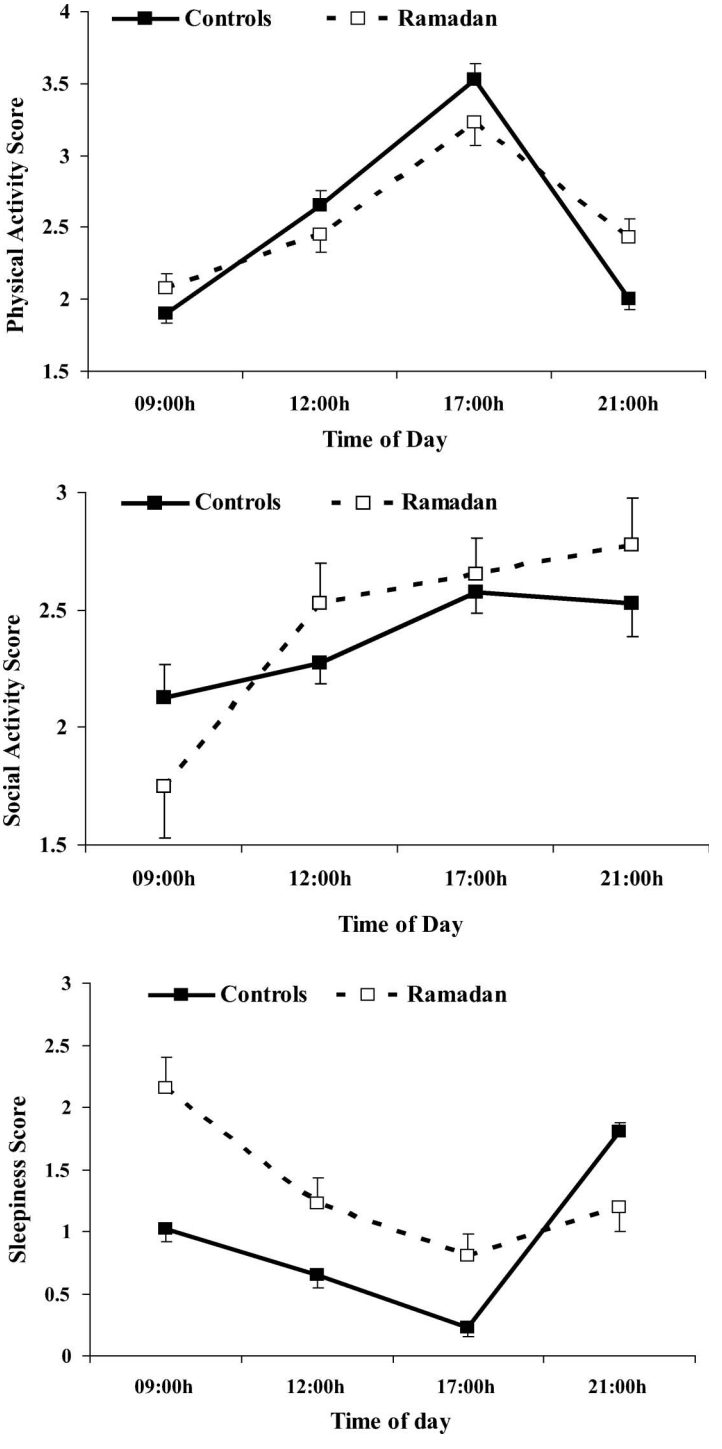

Figure 5. Effect of time of day on control days and Ramadan. Top, Physical activity; middle, Social activity; bottom, Sleepiness.

Table 1. Statistical results from analysis of variance analyses.

	ANOVA			
Variable	Ramadan vs. Controls	Time of Day	Interaction	Comment
Subjective Estimates of Activity and Sleepiness:				
Physical Activity	$F_{1,19} = 0.1$; $P = 0.80$	$\mathbf{F_{2.9,54.9} = 83.3; P < 0.0005}$	$\mathbf{F_{2.5,46.6} = 5.7; P = 0.004}$	See Figure. 5, top
Mental Activity	$F_{1,19} = 2.9$; $P = 0.11$	$\mathbf{F_{2.0,38.2} = 29.4; P < 0.0005}$	$F_{2.2,41.7} = 1.7$; $P = 0.19$	Similar profile to Figure 5, top
Social Activity	$F_{1,19} = 0.1$; $P = 0.78$	$\mathbf{F_{2.1,40.2} = 15.9; P < 0.0005}$	*$F_{2.3,44.5} = 2.7$; $P = 0.071$*	See Figure 5, middle
Sleepiness	$\mathbf{F_{1,19} = 8.3; P = 0.010}$	$\mathbf{F_{1.9,35.6} = 25.5; P < 0.0005}$	$\mathbf{F_{1.8,34.3} = 12.0; P < 0.0005}$	See Figure 5, bottom
Desire for Physical Activity	$F_{1,19} = 2.7$; $P = 0.12$	$\mathbf{F_{2.9,55.4} = 18.9; P < 0.0005}$	$F_{2.8,52.5} = 2.0$; $P = 0.13$	Similar profile to Figure 5, top
Desire for Mental Activity	$F_{1,19} < 0.1$; $P = 0.92$	$\mathbf{F_{2.6,49.7} = 19.8; P < 0.0005}$	*$F_{2.7,51.8} = 2.5$; $P = 0.079$*	Similar profile to Figure 5, top
Urine Osmolality:	$\mathbf{F_{1,19} = 5.3; P = 0.033}$	$\mathbf{F_{1.8,33.8} = 16.3; P < 0.0005}$	$\mathbf{F_{1.8,34.6} = 44.4; P < 0.0005}$	See Figure 6
Physical Measures:				
Grip Strength	$F_{1,19} < 0.1$; $P = 0.82$	$\mathbf{F_{1,19} = 20.1; P < 0.0005}$	$F_{1,19} < 0.1$; $P = 0.82$	17:00 h > 12:00 h
Rise in HR with Exercise	$\mathbf{F_{1,19} = 66.2; P < 0.0005}$	$\mathbf{F_{1,19} = 6.6; P = 0.019}$	$\mathbf{F_{1,19} = 8.2; P = 0.010}$	See Figure 8A
Cadence	$F_{1,19} < 0.1$; $P = 0.86$	$\mathbf{F_{1,19} = 8.4; P = 0.009}$	$F_{1,19} = 2.2$; $P = 0.15$	See Figure 8B
Lactate	$\mathbf{F_{1,19} = 15.9; P = 0.001}$	$\mathbf{F_{1,19} = 112.1; P < 0.0005}$	$\mathbf{F_{1,19} = 9.1; P = 0.007}$	See Figure 8C
RPE	$\mathbf{F_{1,19} = 6.1; P = 0.023}$	$F_{1,19} = 1.8$; $P = 0.20$	$F_{1,19} = 0.3$; $P = 0.59$	See Figure 8D

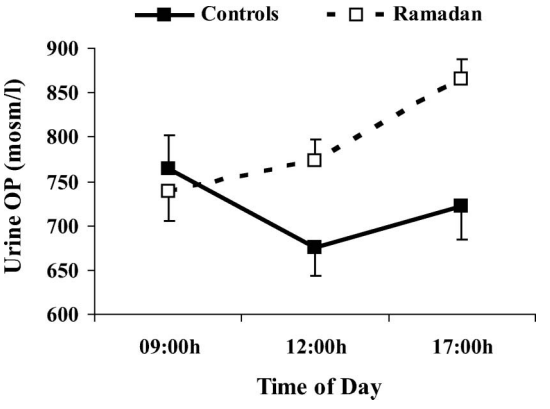

Figure 6. Urinary osmotic pressure (mosm/l) during control days and Ramadan.

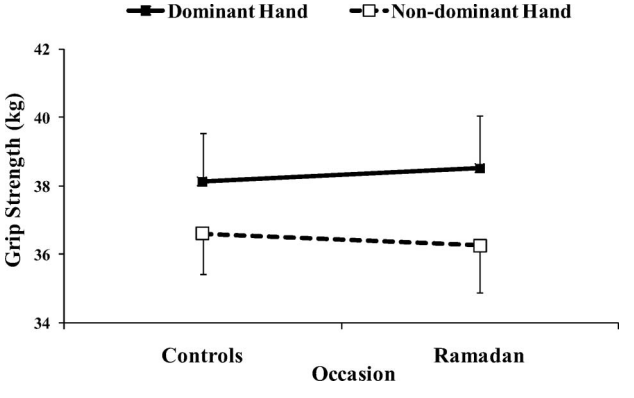

Figure 7. Grip strength in dominant and non-dominant hands on control days vs. Ramadan.

time-of-day effect, with higher values at 17:00 h than 12:00 h (Table 1). When the two hands were compared, the dominant hand was significantly stronger ($F_{1,19} = 14.6$; $P = 0.001$), and there was a significant interaction between Hand x Occasion ($F_{1,19} = 5.3$; $P = 0.033$). This is shown in Figure 7 and indicates that the non-dominant hand tended to be slightly weaker in Ramadan, the dominant hand, by contrast, being slightly stronger.

The responses to the bout of exercise are summarised in Table 1 and Figure 8. Exercise always produced a highly significant increase in heart rate and this was higher on control days. There was also a significant time-of-day effect, the rise being greater at 17:00 h. However, the detailed changes were more complex, as indicated by the significant interaction term (Table 1); the rise in heart rate between 12:00 h and 17:00 h during Ramadan was replaced by a slight *fall* on control days (Figure 8A).

A higher cadence was chosen at 17:00 h (Figure 8B), though there was no significant difference between Ramadan and control days. At 17:00 h also, post-exercise lactate levels were higher; however, Ramadan was associated with lower lactate levels in general and the significant interaction term (Table 1) indicates that

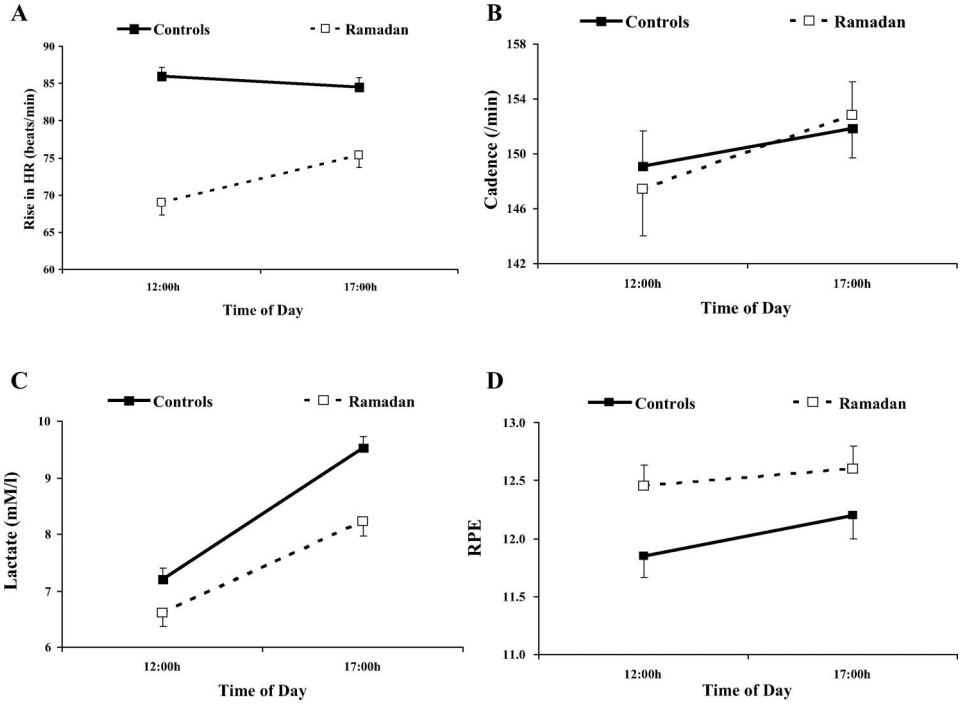

Figure 8. Effects of exercise at two times of day on control days and during Ramadan. A, Rise in heart rate, HR (beats/min); B, Cadence (cycles/min); C, Post-exercise lactate (mmol/l) and D, rating of perceived exertion (RPE score).

the exercise-induced increase at 17:00 h was less (Figure 8C). Subjective estimates of exertion (RPE) did not show a significant time-of-day effect, but were higher in Ramadan (Figure 8D).

Discussion

The results of this study confirm that Ramadan is associated with many changes to an individual's lifestyle, including reasons for eating, general activity and sleep, and also indicate that there are adverse effects upon physical performance and the responses to a bout of mild exercise.

A clear indication of the effects of daytime fasting can be seen by considering daytime changes to urine osmolality and the intakes of fluid and food after sunset (when recuperation from the period of fasting is to be expected). The osmolality of the urine provided evidence of progressive dehydration during the course of the daytime (Figure 6) but, in the evening, all participants drank copiously; at this time also, they ate a substantial meal. The reasons given for these increased intakes of fluid and food were "thirst" and "hunger" as well as an acknowledgement of the need to recuperate from daytime fasting (Figures 3, bottom, and Figure 4). The main types of fluid drunk, water, fruit juice and milk (Figure 3, top), would all aid rehydration. Rehydration would also be promoted by drinking caffeine-containing beverages (fizzy drinks, tea and coffee) in far less quantities, if at all, during Ramadan. This selective intake in different types of fluid has been observed before

(Waterhouse et al. 2008a); it is possible that it is part of the culture of those living in a hot country to imbibe less frequently drinks that cause diaphoresis and diuresis, so increasing the rate of rehydration.

Participants went to bed later in Ramadan, and spent less total time in bed (Roky et al. 2003; Margolis and Reed 2004; Waterhouse et al. 2008a, 2008b). The later retiring time might have contributed to the greater ease of getting to sleep in Ramadan. However, the participants in the present study also tended to rise *later* rather than earlier in Ramadan, possibly a reflection of their lack of domestic commitments (they were males and lived at home with parents). Participants ate meals in the evening that were larger than normal and also ate just before retiring, claiming that this helped them get to sleep. The quality of sleep has been shown to change in Ramadan (Roky et al. 2003) but possible interactions between time of retiring, amount and timing of food eaten and quality of sleep need further investigation.

Participants felt sleepier in the daytime but this increase did not extend into the evening (Figure 8C). In spite of the increased daytime sleepiness, however, participants did not nap during the daytime, citing "too busy" as the reason (Figure 2). This result differs from some that have been published (Margolis and Reed 2004), including our own (Waterhouse et al. 2008a, 2008b), and reflected the individual's daytime commitments at the Sports Academy, with little opportunity to catch up on lost sleep.

As a result of the above changes in fluid and food intakes in the daytime and altered sleep at night, participants would have been suffering from the effects of partial sleep loss and fluid and food deprivation, and this would be predicted to affect negatively mood and mental performance, and responses to physical activity (Waterhouse et al. 2001; Reilly and Edwards 2007; Reilly and Waterhouse 2007). Subjective estimates of the amounts of physical and mental performance carried out, and the desire to undertake them (Table 1 and Figure 5, top), all showed that Ramadan was associated with decreased activities in the daytime but increased values in the evening after sunset. Such results have been found and discussed previously (Kadri et al. 2000; Karaagaoglu and Yucecan 2000; Roky et al. 2000; Waterhouse et al. 2008a, 2008b). We interpret the current results as further evidence of the changes to daily life produced by the demands of Ramadan as well as a validation of the present protocol and participants. Social activities also changed in Ramadan, being higher throughout the daytime as well as the evening (Figure 5B). Higher daytime values in Ramadan differed from our previous findings (Waterhouse et al. 2008a, 2008b), and probably reflects the fact that the participants were younger, male, lived with their parents and had few domestic responsibilities. (Our previous studies had been upon individuals who were housewives or students living alone.)

Physical ability and the response to exercise are changed in Ramadan, but the effects are complex (Table 1 and Figures 7 and 8). The dominant hand produced greater strength than did the non-dominant hand, and afternoon values were higher than those produced at noon, results that were to be expected (Reilly et al. 1997). However, there was a difference between the two hands, the non-dominant hand appearing to be more susceptible to negative effects during Ramadan. A difference between the dominant and non-dominant hands has been observed before using a task requiring hand–eye coordination (Edwards et al. 2008). The difference between the two hands might reflect the relative roles played by neural and muscular components and their susceptibilities to fasting and sleep loss, but this speculation needs further investigation.

With regard to the response to mild exercise, time-of-day effects were present in the rise of heart rate caused by it, the cadence chosen during the exercise and post-exercise blood lactate levels (Figure 8). It should be remembered that the circadian rhythm of HR, which peaks around the early afternoon, leads that of core temperature, which peaks in the late afternoon (Reilly and Brooks 1982, 1986); as a result, the HR in the current study would have been around its peak at 12:00 h but decreasing by 17:00 h. The rise in cadence between 12:00 h and 17:00 h is commensurate with a rise in core temperature and effects of this rise upon metabolic activity (Thomas and Reilly 1975); such a rise in metabolic activity between 12:00 h and 17:00 h could also explain the rise in lactate (Forsyth and Reilly 2004, 2005).

Ramadan caused changes in the mean rises in heart rate and blood lactate, but whether these arise from the effects of sleep loss, the metabolic consequences of dehydration and lack of food intake and/or some other factor(s) cannot be determined from the present results. The lower rise of HR in Ramadan is compatible with a lower sympathetic drive commensurate with energy disturbances during Ramadan, and has also been observed following sleep deprivation (Reilly and Edwards 2007). The lower lactate values when fasting are attributable to a greater use of lipids as fuel at this time (Leiper et al. 2003; Roky et al. 2004; Benaji et al. 2006; Reilly and Edwards 2007; Reilly and Waterhouse 2007).

The finding that the perception of load was increased (Figure 8D) in spite of *decreased* rises in heart rate and lactate accords with the subjective estimates of a decreased amount of physical work performed and wished for in the daytime (Figure 5, top and Table 1). Also, the statistically significant interaction between Occasion (Ramadan vs. control days) x Time of day for blood lactate and rise of heart rate (see Table 1 and Figure 8A,C) suggests that the effects of Ramadan (whatever their cause) worsen as the day proceeds. These greater "stresses" when performing physical activity later in the day are in contrast to the normal condition, where physical performance at 17:00 h would be expected to be better than at 12:00 h and less demanding physiologically, biochemically and mentally (Reilly et al. 1997; Reilly and Edwards 2007; Reilly and Waterhouse 2007).

In summary, Ramadan makes many demands upon those involved, and is responsible for changes in nocturnal sleep and daytime sleepiness and behaviour. These daytime changes include both actual and desired physical and mental activities and social interactions. There is also evidence that a given bout of physical performance at the end of the daytime fast places a greater burden on the body and is perceived as being more demanding than is the same bout of activity performed earlier in the daytime. Nevertheless, individuals recuperate after sunset by eating and drinking more, and their intake of fluid tends to exclude drinks which would promote further dehydration. The results have clear implications for individuals performing physically-demanding tasks late in the daytime in Ramadan, when effects due to fatigue and dehydration will be more marked.

A limitation of this type of field study is the restricted amount of time available for testing participants, particularly if they are busy with a full schedule of daytime activities. This limitation extends to the type of task that can be investigated and its relevance to the demands and requirements of daily life; grip strength, for example, is of only limited value. Using tasks that are more relevant to daily life generally requires participants to be investigated in a laboratory environment. Current work in our group of the effects of fasting as is required in Ramadan include undertaking such studies.

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